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Rainvision: the impact of road markings on driver behaviour – wet night visibility

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Abstract

Previous European research, i.e. COST 331 and the IMPROVER projects had demonstrated that road markings greatly increase driver comfort during dry night time conditions. Nevertheless, they highlighted the need for additional research under wet and wet and rainy conditions.
Building upon this research, the RAINVISION project has investigated over the last three years how road markings can influence driver behaviour under all nightime weather conditions (dry, wet and wet and rainy) and how different age groups and gender groups adapt their behaviour based on the visibility and retro-reflectivity of road markings. The project has carried out three different trials; i.e. a simulation trial in France, a track test trial in Austria and on-road trial in the United Kingdom in cooperation with local authorities. For the simulation and track test trials, more than 100 test subjects were recruited respectively according to three age groups (20–40, 41–60 and 61+ years) and took several trials during different conditions. For the on-road trials, 10 high--risk sites were selected in cooperation with Durham county and Type II marking materials were applied in these sections. The project subsequently monitored speed over a whole climatic cycle and undertook an accidentology analysis. The results of the study in general indicate that the presence of enhanced road markings did significantly increase driver comfort, especially for older drivers. While there was an increase in driver speed, it was not seen as safety hazard as it was compensated by greater preview times. In fact in the UK trials, the results show that the presence of enhanced road markings actually led to a decrease in speeds.

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1. Introduction

Previous research (e.g. COST 331,1991) and studies (IMPROVER, 2006) have confirmed that the night visibility of road markings is an essential contributor to driver comfort and road safety. Nevertheless, road markings are often neglected, in many cases have even completely disappeared from roads.

At the same time, as Europe's population is ageing, the percentage of older drivers on Europe's road is expected to increase significantly. Given that older drivers are more likely to have more accidents caused by to visual constraints than younger drivers, it is important to gain a better understand how core infrastructure elements such as road markings need to be adapted to serve the visual needs of a increasly ageing population.

In this context, and capitalising on previous projects, RAINVISION studied the influence of road markings on driver behaviour, by mainly analysing how different age groups (young vs. middle vs. old) and different gender groups (male vs. female) adapt their driving behaviour on the basis of the visibility and retroflectivity of road markings under three weather conditions, (i.e. dry, wet, wet and rainy) during night time driving.

To arrive at its conclusions, the project undertook three sets of trials, i.e. simulation driving in France, a track test in Austria and an on-road trial in the United Kingdom. This paper outlines the results of these three trials, offers some conclusions, highlights the limitations of the study and provides pointers for future research.

2. Simulation studies

2.1. Description of trials

The simulation trials were carried out on the premises of Aximum (who was the partner responsible for this trial) and COLAS (which is the parent company of Aximum). Both trials took place in the vicinity of greater Paris.

A total of 123 subjects were recruited and tested as drivers on the driving simulator through several sessions (Table 1). The requirements for the recruitment were that people should be aged at least 20 years old, should have hold a class B driving license for a minimum of two years and should usually drive a vehicle on a daily basis. Subjects were split into three age categories as shown below:

Table 1. Sample sizes for simulation sessions by age group.

Class of age	Raw number of drivers	Selectednumber of drivers
20–40	47	45
41–60	41	40
+ 60	35	34
TOTAL	123	119

Gender	Raw number of drivers	Selected number of drivers
Male	69	68
Female	54	51
TOTAL	123	119

To avoid biased results, subjects had to undergo a series of visual tests: binocular acuity for long distance vision; stereoscopic vision; colour and contrast perception; mesopic vision and glare (vision recovery time).

Subsequently, participants were asked to drive on a simulated rural single carriage way environment under two driving scenarios, i.e. one with standard markings and a second with enhanced markings.

To determine the impact of the road markings on driver behaviour, the study assessed the number of run-off incidents during the trials, i.e. occasions where the vehicle would either deviate from the boundaries of the road either by crossing into the opposite lane or cross the edge line.

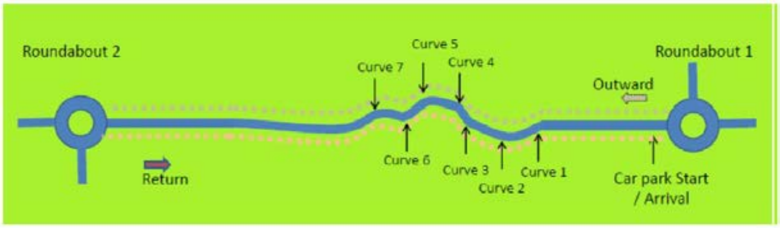

Fig. 1. Simulated environment of the road.

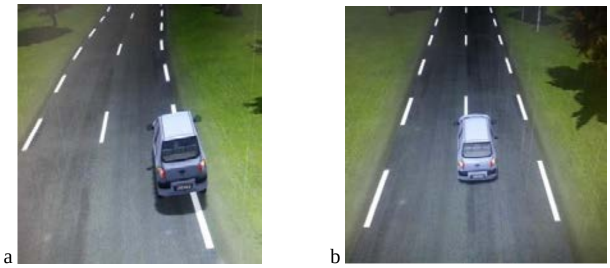

Fig. 2. Screenshot of vehicle crossing edgeline and into opposite lane.

2.2. Results

A subsequent analysis of the results found that the number of errors committed by subjects when driving under the standard road marking scenario was 70% percent higher compared to the enhanced road marking scenario. When looking at the effect by age group, the results showed that the improvement in the visibility of road markings made a big difference in terms of driver comfort forthe groups 21–40 and 61+ years, but did not appear to have an impact for the intermediary age group 41–60 years.

3. Track test in Austria

3.1. Description of test track

The track test was carried out near the Austrian city of Melk, on the premises of the Austrian Automobile club (ÖAMTC). A track route was selected in a way that potential differences of marking levels could be identified by means of driving data (speed, lateral and longitudinal acceleration). Test subjects completed the track in clockwise driving direction.

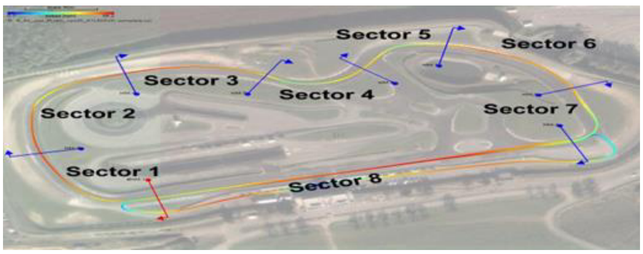

Fig. 3. The test track with marked sectors.

The total length of the track route where test subjects had to drive was approx. 980 m (3215ft). Test drives were carried out with three different marking conditions:

- non-reflective=baseline,
- marking material I=reflective material, i.e. RL (dry) 570–685 mcd/m² lx (exceeding Class R5 in EN 1436)
- RL (wet) 3–12 mcd/m² lx (RW0 = no wet reflectivity performance according to EN 1436)
- marking material II=wet reflective material, i.e. RL (dry) 407–572 mcd/m² lx (exceeding Class R5 in EN 1436) and RL (wet) 43–112 mcd/m² lx (Class RW2 – RW4 in wet reflectivity performance according to EN 1436)

In addition, subjects drove under three different driving conditions: (dry, wet and wet & rainy), carried out during one week.

The coloured line (Figure 1) symbolises the route that was chosen on which test subjects had to drive. Furthermore, the track was segmented into eight sections to be able to perform an analysis in a sector-wise manner. This approach was chosen as a sector can be understood as one semantic driving task/unit, i.e. representing driving through a left or right bend or a straight.

The wet condition was realised by wetting the road surface with sprinklers. The wet & rainy condition was set up by specially prepared sprinklers which were adjusted in a way that the water moistened not only the track, but also the windshield of the test vehicles.

As the driveway of the test track is wider than a typical rural road, the different marking materials were applied in such way, that a narrow rural road was simulated. As such, the marked road was about 5 m (16ft 5in) wide, each lane 2.55 m (8ft 4.4in) wide.

3.2. Study design

In order to study the impact of the visibility of different pavement markings in different conditions (night time driving in wet and rainy circumstances), also taking into account different age groups, a number of onsite tests was carried out. The test investigates a number of parameters, such as road characteristics (straight road, left and right turns), different simulated weather conditions and sex/age groups. Drivers´ performance was investigated in the three test conditions defined above:

A total of four identical and representative vehicles (Ford Fiesta, 1.25 l, petrol-driven) were used to carry out the track tests.

The data logger used within this study was an off-the-shelf data collection system, a small black box which allowed the capturing of vehicle and video data. This device with its connected two small cameras allowed for an unobtrusive installation in the test cars, as the box was installed under the passengers´ seat. Beside the collection of GPS data, 3-axis accelerometer data (100Hz) was also collected.

Drivers took nine runs in total through specifically chosen road sections, completing the track in the three described driving situations: dry, (1), wet (2) and wet & rainy (3).The design was set up for analysing three age groups: 20–40 year, 41–60 year and 61+ year old drivers, both male and female.

The sample (n=88) was randomly split into two groups A and B, where group A consisted of 46 subjects and group B of 42 test subjects. This approach allowed testing for possible positional effects. Hence, the following test design was realised (Table 2):

Table 2. Order of test runs for group A and B.

	Condition		
	baseline	marking material I	marking material II
Group A	test day 1	test day 2	test day 3
Group B	test day 3	test day 1	test day 2

The advantage of such a counter balanced design is that it makes an experiment more efficient and helps keep the variability low. This helps to keep the validity of the results higher, while still allowing for smaller than usual subject groups.

Test subjects were told to drive the same way they do in real traffic circumstances, especially regarding speed choice. Furthermore, they were instructed to only use the low-beam headlights to ensure comparable visibility of markings. Otherwise it would have been difficult to compare e.g. specific sectors if some test subjects used high--beam headlights where other subjects used low-beam light.

3.2.1. Participant selection

In order to ensure that possible performance differences in the later carried out track test are not due to test subjects´ level of driving fitness, a psychological test battery from was applied. The test battery consisted of three different tests: visual orientation, tachistoscopic traffic perception as well as reaction and motor time. The time taken to complete the test battery was about 30 to 45 minutes.

From 120 potential candidates 88 were chosen to take part in the track test study. The decision to in- or exclude potential test subjects was based on test performance, i.e. if a test subject reached an extremely high or low score in any of the tests, then the person was left out for the track test. This approach ensured that the test performance on the track is not due to extremely bad (or good) visual or psychological skills.

3.3. Evaluation methodology

Due to the design of the study, either general linear models (GLM) for repeated measures or multivariate analysis of variance (MANOVA) for repeated measures were chosen. In principal, the repeated measures design (also known as a “within-subjects” design) uses the same subjects with every condition of the research. In the current research project, the repeated measures represent individual measures for different track and marking conditions.

3.3.1. Questionnaire data

In order to get an impression of how the test participants perceived the different track and marking conditions, a questionnaire was filled out directly after test persons completed all three runs (dry, wet, wet & rainy) for every marking condition (baseline marking, marking material I and II).

Beneath socio-demographic variables which have been described earlier, the questionnaire was used to collect subjective data for every specific track and marking condition in terms of comfort and stress level for every undertaken trip as well as clearness and irritation tendency of the road course. Additionally, the participants were asked to assess the track trajectory in terms of perceptibility and demand on attention level. The questionnaire was presented by means of the following opposite pairs of characteristics:

- comfort (comfortable vs. uncomfortable)
- stress (unstressed vs. stressed)

The first two pairs of opposites were asked how test persons perceived the trip as a whole, whereas the next four pairs were used to assess the track trajectory:

- clearness (well-arranged vs. unclear)
- confusion (non-irritating vs. irritating)
- perceptibility (apparent vs. non-apparent)
- attention (attention-grabbing vs. unobtrusive)

3.3.2. Driving data

From the test runs, not only questionnaire data but also data from actual driving behaviour was obtained. The collected data was retrieved from the data logger which is described under section 3.2.

In order to compare driving behavior under different track and marking conditions, driving parameters such as speed, longitudinal and lateral accelerations were collected.

3.4. Results

The results from the track test indicate that driving comfort as well as clearness and perceptibility of track trajectory was assessed best when marking material II (wet-reflective) was applied on the track.

In unknown driving circumstances, especially when there is no road marking, an application of marking material surely provides more driving comfort, decreasing the driver's uncertainty when following the roadway. This holds especially true in adverse weather condition, e.g. at nightime wet and/or rainy conditions as can be shown in the graphs below:

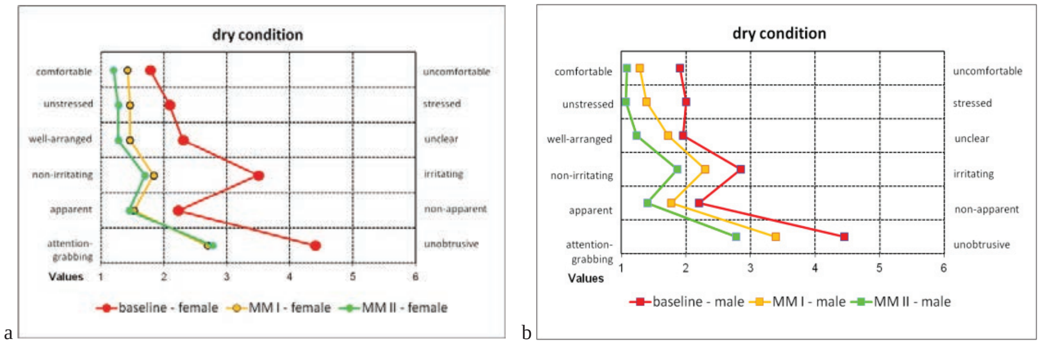

Fig. 4. Mean questionnaire values of female/male subjects for different marking conditions, dry.

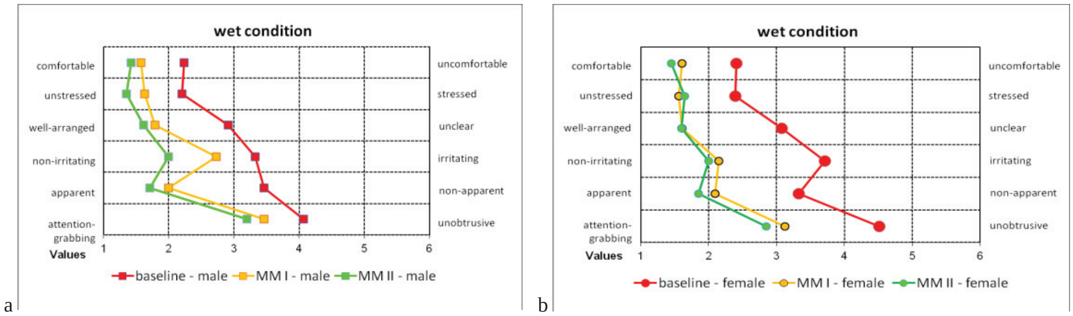

Fig. 5. Mean questionnaire values of female/male subjects for different marking conditions, wet.

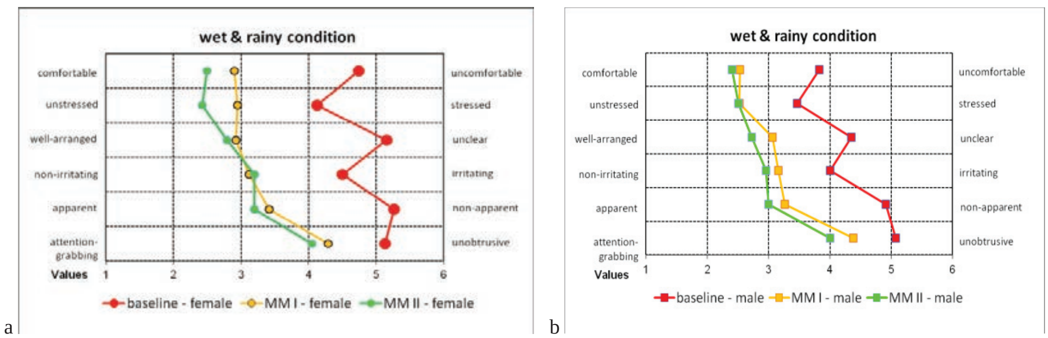

Fig. 6. Mean questionnaire values of female/male subjects for different marking conditions, wet/rainy.

Given that there is a correlation between a drivers perception of the road environment and road safety, it can be concluded that the more salient a marking material is perceived, the higher the subjective comfort and safety is experienced.

Regarding driving behavior by means of speed choice (measured as lap times), test subjects drove slowest in the baseline condition, faster under condition with applied marking material I (dry reflective, type I), and slightly faster under condition with applied marking material II (wet reflective, type II). This result holds especially true for older persons like the subjects in the oldest age group in this study as an age interaction could be observed here.

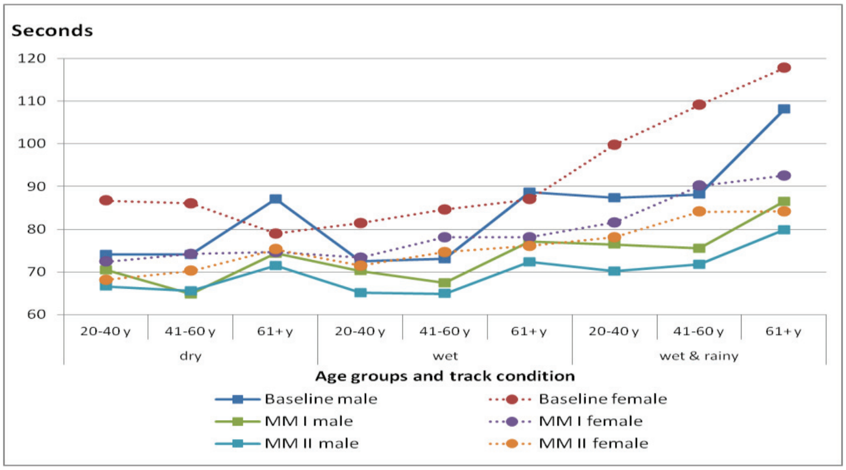

Fig. 7. Mean lap times for different age groups and marking conditions by sex.

As the lap times can be interpreted as “time needed for solving the driving task” it can be concluded that it takes significantly longer for aged persons to grasp the driving situation and/or the driving path under adverse conditions when there is no road marking. The higher speed should not be generally associated with a reduction in traffic safety. The speed increase was small and obviously well balanced with the increased visibility of the road marking material. Both stress and comfort level of the test subjects was lower with the higher speeds. The differences in speed remained on a generally low level between condition marking material I and marking material II, equaling to 2–5 km/h (approx. 1–3 mph) difference on the whole track on average. Compared to the baseline marking, driving speed was higher in both marking conditions.

Analysing the speed behaviour of older drivers, we can conclude that the more adverse the driving and/or weather conditions are, the driving task gets disproportionally complex for older drivers. In order to neutralise this disadvantage i.e. situation complexity for older drivers, establishing road markings at non-equipped locations could make traffic situations more fair and solvable for this group of traffic participants.

When analysing driving behaviour in terms of mean lateral and longitudinal accelerations, no statistically significant differences occurred after controlling for lap time or sector time. If time/speed it isolated from lateral accelerations, the remaining parameter is curve radius. As no significant differences occurred after controlling for time/speed, subjects did not follow the track trajectory differently in various conditions by means of different driven radius, e.g. cutting corners.

From the track test, it finally can be concluded that wet-reflective marking material (type II) does increase driving comfort. With respect to the increase in speed, the conclusion is that it should not be seen as a safety hazard given that it is compensated by better preview time confirming the finding of previous research, i.e. Higgins et al. and Schnell et al.

4. On road trials in the United Kingdom

4.1. Description of trials

The trials in the United Kingdom were carried out in cooperation with the Durham Council in the North of England.

As a first step, high risk sites with a high accident history linked to visibility and thussuitable for application of high performance materials were identified in cooperation with Durham City Council. A total of ten sites were identified as shown in the table below:

Table 3. Description of test sites.

Site No.	Speed limit	Group	Road type	Location type
1	60	B	Straight	Rural
2	30	A	Semi-straight	Urban
3	30	A	Straight	Urban
4	60	B	Straight	Semi-urban
5	30	A	Semi-bendy	Urban
6	60	B	Semi-straight	Semi-urban
7	60	B	Straight	Semi-rural
8	60	B	Straight	Semi-rural
9	30	A	Semi-bendy	Urban
10	60	B	Semi-bendy	Semi-rural

Subsequently, an initial data collection of accident statistics over the previous 12 months and driver baseline speed data was established prior to the launch of the trials. This was done by installing pneumatic tubes and data was collected for a total period of four weeks (25 June 2012 – 23 July 2012).

Fig. 8. Example of installed speed measurement pneumatic tube.

Once the baseline driver speed has been established, cameras were installed in the locations and speed was monitored over a whole climatic cycle. At the same, wet-night reflective markings were installed on the location and speed was monitored over a full climatic cycle which allowed for a before after analysis of summer 2012 vs summer 2013 and winter 2012 vs winter 2013.

4.2. Results

The results of the on road trials seem to contradict the established knowledge with respect to road markings and safety. While the presence of road markings is generally associated with higher speeds, the results of the trials actually found that the average speed was actually lower by 3.2 km/h (approx. 2 mph). At the same, while one would have expected accident figures to be lower, there was actually in increase in number from 14 to 21 accidents. An analysis of the official police crash records concerning the cause of the accident could not however link any of the accidents to road markings, all of them being attributed to other causes such as slipperiness of the road, alcohol consumption, etc.

5. Overall conclusions/recommendations, limitations and future research

The RAINVISION project sought to advance the state of the art in road markings research by analysing the impact of road markings on driver behaviour during three night time conditions and taking into consideration the visual needs of an increasingly ageing population.

Of the three trials, the most comprehensive was the track test which allowed for in-depth analysis of several factors relevant to the study, i.e. speed, lateral acceleration, participants' perception of the different road markings etc. This trial clearly demonstrated that applying retro-reflective pavement marking material has a positive effect on the subjective feeling of safety of drivers, especially in adverse weather/driving conditions which were simulated in this experiment. Under night-time und rainy driving conditions, the marking material II (wet retro-reflective material) ensured clear trajectories of the driving path, thus providing anticipatory stimuli of road environment and taking substantial workload off the driver.

These results were largely confirmed by the simulation trials which found that errors committed by drivers when road marking were less visible, increased by 70%. However, the simulation software did not allow for a number of important parameters to be captured (e.g. speed, acceleration) which would have allowed for a more holistic assessment of the impact of better markings.

Concerning the on-road trials, and as mentioned above, the results contradicted the findings of the two previous trials given that average speed actually decreased after the installation of better markings and the number of accidents increased, even though an analysis of police records could not link this increase to better markings. The main shortcoming of the on-road trials is that it was not possible within the budget allocated to the project to actually monitor the drivers driving patterns in detail – as is done in major Field Operational Tests (FOTs) or Naturalistic Driving (ND) studies-, which in turn would have given the project a more in-depth understanding of the impact of road markings on driver comfort.

One of the core recommendations of the projects, which stems from the previous research results as well as an extensive literature review of existing practices on European roads, is to establish a intervention and maintenance standard for road markings of 150 mcd/lux/m^2 (R3) during dry conditions and 35 mcd/lux/m^2 (RW2) for wet and rainy conditions, that should apply to all TEN-T and major A-roads. In addition, it recommends a minimum width of 150 mm for these markings based on finding from Carlson et al.

Such an intervention and maintenance standard is expected to provide an increasingly ageing driver population sufficient preview times to compensate for their reduced visual abilities. At the same, this recommendation has been endorsed by EuroRAP as one that would also guarantee reliable operation of Lane Departue Warning (LDWS)/Lane Keeping Assistance (LKA) Systems which are gradually being introduced in new vehicles.

In terms of future research, there is a need to perform additional research, mainly in the form of field studies(FOT and/or ND), to be able to arrive at a definitive intervention and maintenance standard for LDWS/LKA systems in order to take advantage of the important safety gain that can be expected from the introduction of such systems. Current proposals have been based on extensive desk research, yet real-life information is needed to understand how such systems work under different weather conditions and how road markings can ensure their reliable performance.

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